THE INFLUENCE ON MAN OF A LONG STAY UNDER CONDITIONS OF REDUCED BAROMETRIC PRESSURE AND RELATIVE ISOLATION

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Assuring the vital activity and capacity for work of man on long flights in present and future flight apparatus is one of the central problems of aviation and space flight. This problem involves a complex set of questions, among which the following are important: selection of the best pressure regime within the space ship, establishment of the proper daily rhythm of work and rest for the astronaut, prolonged isolation, etc. /269

At the time the present study was undertaken (1958) there were only scattered references in the literature to certain works which discuss the possibility of man remaining for a long time (up to four days) in an environment with a modified gas composition and reduced barometric pressure (A.P. Apollonov, D.I. Ivanov, M. Ye. Marshak, and V.A. Spasskiy,).

In addition to this we were also acquainted with the work of A.M. Genin, O.G. Gazenko, A.D. Seryapin, N.N. Gurovskiy, and others, which showed that man could remain for 10-15 days in relatively small chambers at reduced barometric pressure (elevation 5000 m). There was also information concerning an experiment carried out by the American flyer Farell, who remained for 7 days in a barochamber of small size (2.5 m^3) at a height of 5500 mm. This experiment studied, in addition to the effects of rarefaction, the influence of specially developed "daily" cycle (14.5 hr).

The work described above should be considered as a first attempt to solve experimentally the question of choosing proper pressure conditions within the cabin of a space ship and the scientific establishment of a regime of sleep and wakefulness for the astronaut.

Selection of the proper pressure conditions in the cabin of a spaceship requires that one take into account both the engineering and the medical aspects. The first aspect involves the weight and strength of the cabin. The second concerns the conditions of human life. Available data in the field of aviation physiology have provided a basis for assuming that one of the appropriate pressure regimes in the cabin may be a pressure of 380 mm Hg (a height of 7000 m). But the question of a prolonged stay under these conditions has remained open and has been in need of experimental solution. The permissibility of a very thin atmosphere for these purposes is related to the hazard of the development of decompression disturbances. /270

The studies undertaken by us had two goals:

— to study the possibility for man to remain for a long time (up to 30 days) in small chambers with reduced atmospheric pressures corresponding to heights of 3000, 5000 and 7000 m, with the pO_2 in the air ranging between 150 and 200 mm Hg; and

— to determine the nature and direction of functional changes in relation to disturbances of the normal daily regime.

Method of Investigation

The studies were carried out in a specially outfitted pressure chamber with a net volume of 5 m^3. The gas composition of the atmosphere, the temperature regime, and the humidity were maintained within given limits with the use of regeneration apparatus. Two persons participated in the experiment simultaneously. An individual daily regime was worked out for each of them, and each alternated in repeated experiments. The duration of the experiment ranged from 10 to 30 days. The general pattern of the experiment and the daily regime are shown in the following schedule.

Time of day	Regime No. 1	Regime No. 2
9.00	Enters on duty	Goes of duty
9.10—9.50	Physiological and hygiene studies	
9.50—10.30	Breakfast	
10.30—11.50	Clinical studies	
12.00—14.00	Duty	Daytime sleep
13.30—14.00	Physiological and hygiene studies	
14.30	Dinner	
15.00—17.00	Daytime sleep	Duty
17.00—19.00	Clinical and hygiene studies	
19.30	Supper	
20.00—20.30	Physiological and hygiene studies	
20.30	Duty	Night time sleep until 2:30 AM
1.00—2.50	Clinical and hygiene studies	
3.00	Night sleep until 9 o'clock	On duty until 9 o'clock
5.00—7.00	Physiological and hygiene studies	

The subjects being studies were fed with preserved and concentrated food products with a vitamin complex added.

Observations were made during the experiment on certain aspects of higher /271
nervous activity (behavior, residual time reflex, critical frequency of flicker

fusion, visual perception time, color perception, and differential time thresholds), electroencephalograms, electrocardiograms, breathing, arterial pressure, body temperature, reaction of the cardiovascular and respiratory systems to measured physical stress also with restrained breathing, energy consumption of the organism (after Holden), protein fractions in the blood plasma (by the electrophoresis method), and the content of 17-oxycorticosteroids in the urine. The electroencephalograms were recorded with mono- and bipolar leads from the occipital and frontal regions and were subjected to frequency analysis. We also determined the total EMF, the EEG, and the EMF of individual components of the EEG rhythms.

The program also provided for detailed clinical and physiological examination of the persons taking part in the experiment. The hygienic studies (barometric pressure, content of O_2 and CO_2, temperature, and humidity) were done 6 times per day.

Results of the Investigation

Seven persons took part in the study. Table 2 and Figs. 1 and 2 give a general description of the experimental conditions, the length of the experiment, and the results.

It is apparent from the data given that pO_2 in the expired air ranged from 150 to 200 mm Hg; the pCO_2, from 2 to 14 mm Hg; the air temperature in the pressure chamber, from 18 to 27 C; and the relative humidity, from 30 to 75%. In particular cases the relative humidity dropped to 10-30%.

Figure 3 gives comparative data on changes in pulse frequency, breathing, and the arterial pressure in experiments at heights of 3000, 5000, and 7000 m, lasting 10 days.

The changes observed under these conditions did not exceed physiologically permissible limits. Analysis of the EKG's showed that under the conditions of the experiment changes were observed in the position of the electrical axis of the heart.

Maximum deviation of the cardiac axis to the left (from 13 to 30°) was observed at a height of 7000 m, a phenomenon associated with the higher position of the diaphragm (height meteorism). Sometimes the position changes of the cardiac axis were more complex in nature, as indicated by the simultaneous increase of the R peak at all three leads.

The electroencephalograms showed no changes indicating an effect from atmospheric rarefaction within the limits of the studies. Periodic variations in the α and β rhythms (14-20 Hg) are of interest, as well as the total EMF of the EEG as a function of the time of day at which the record was made.

From a frequency analysis of the EEG it was found that slow waves of the /272
delta type are a constant component of the electoencephalogram during the period of wakefulness both during the day and at night. As for the number of these

Certain Parameters in the Pressure Chamber

Dates of the experiment	Last name of subjects	"Height", m	pO_2, mm Hg	pCO_2, mm Hg	Relative humidity of the air, %	Air, C°	Length of stay, days	Daily regime of subject	Remarks
March 15-28	P-n	3000	150-180	2-13	40-70	20-24	13	No. 1	Experiment concluded upon completion of program
The same	P-v	3000	150-180	2-13	40-70	20-24	13	No. 2	
April 18-28	Pod-v	5000	150-190	2-8	45-68	18-24	10	No. 2	The same
The same	F-k	5000	150-190	2-8	45-68	18-24	10	No. 1	The same
July 22-August 1	Pod-v	7000	156-175	3-14	50-60	25-26	10	No. 1	The same
The same	F-k	7000	156-175	3-14	50-60	25-26	10	No. 2	The same
May 24-June 23	P-n	3000	160-200	2-12	50-75	20-27	30	No. 1	The same
May 24-May 29	P-v	3000	160-200	2-12	50-75	20-27	4	No. 2	Removed from pressure chamber with elevated body temperature
May 30-June 9	D-v	3000	160-200	2-12	50-75	20-27	10	No. 2	
June 13-23	K-n	3000	160-200	2-12	50-75	20-27	9	No. 2	Upon conclusion of experiment
November 15-December 16	F-k	7000	150-200	2-12	30-45	20-23	30	No. 2	Experiment concluded upon completion of program
The same	K-n	7000	150-200	2-12	30-45	20-23	30	No. 1	

Dererioration in the condition of subjects P-v and D-v was the result of factors not directly related to the condition of the experiment.

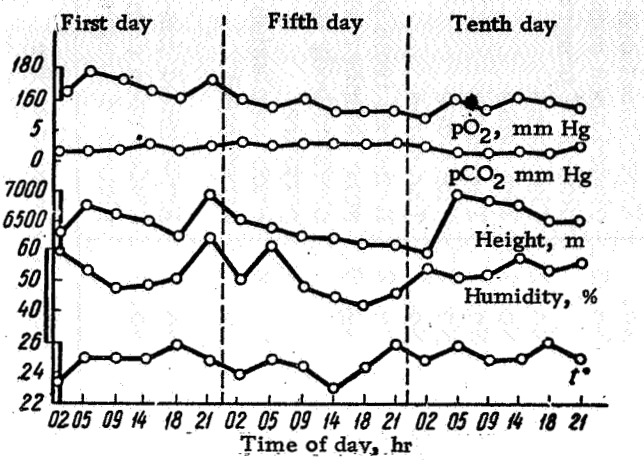

Figure 1. Changes in the Microclimatic Indexes in the Pressure Chamber on the First, Fifth, and Tenth Days of the Experiment

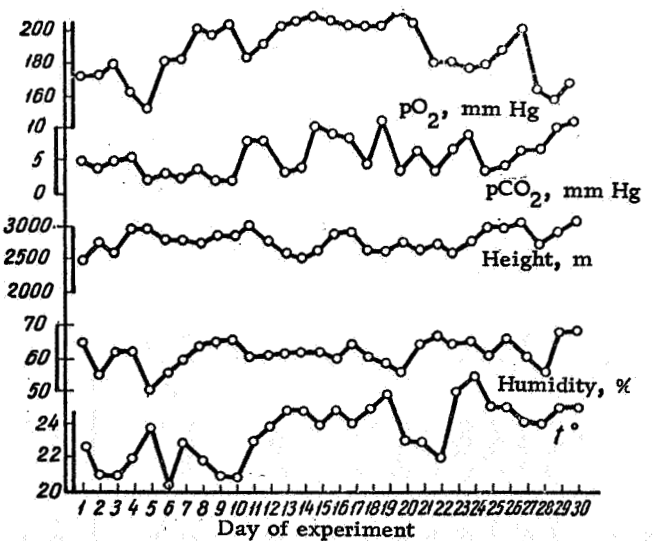

Figure 2. Changes in the Microclimatic Indexes in the Pressure Chamber During a 30-Day Experiment (Measurements at 9 AM).

waves, this was very variable. In evaluation of the nature of the EEG it is apparent that the deviations observed at all heights were for practical purposes within normal limits. Nor were any appreciable deviations observed in a study of the delayed (20 sec) motor time reflex. The changes observed were individual in nature and did not exceed the magnitudes observed under conditions of ordinary activity of the subjects. A greater variability of the time curve of the reflex could only be observed toward the end of the experiment (according to the data of V.T. Lebedeva).

Figures 4 and 5 show the changes in the critical frequency of flicker fusion and differential time thresholds in subjects P-n and P-v in a 30-day experiment at a height of 3000 m. It is apparent that in the case of subject of P-n there is reduced function during the first 10 days and, in the succeeding period beginning with the 15th day, there was a contrasting increase. This variation in function evidently reflects a reconstruction process of the organism.

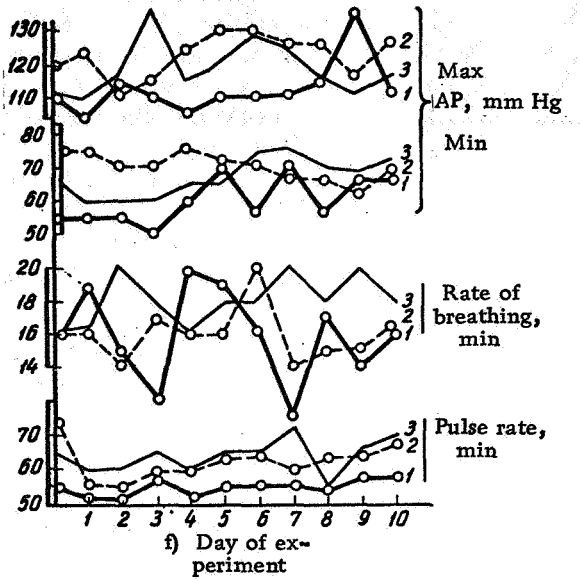

Figure 3. Change in Arterial Pressure (A P), Frequency of Cardiac Contractions and Motor Movements in Subjects P-n and Pod-v During Prolonged Stay at Heights of 3000 (1), 5000 (2), and 7000 m (3).

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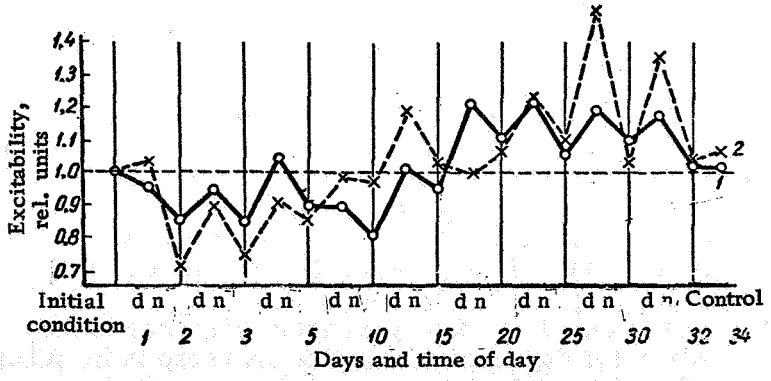

Figure 4. Critical Frequency of Flicker Fusion (1) and Time Differential Thresholds (2) in Subject P-n During Prolonged Stay in the Pressure Chamber at a Height of 3000 m.

Note: d = day and n = night.

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In the case of subject P-v (Fig. 5), on the other hand, the sort of phasing is not observed. The critical frequency of flicker fusion and differential time thresholds during the entire period of his stay in the pressure chamber are lower.

This fact indicates, probably, a progressive reduction of function. The first subject followed daily regime no. 1, and the second, regime no. 2.

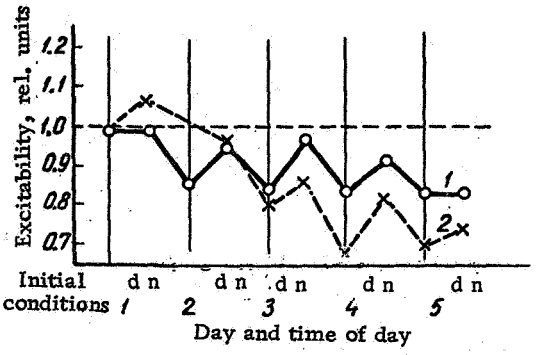

Figure 5. Critical Frequency of Flicker Fusion (1) and Time Differential Thresholds (2) in Subject P-v During Prolonged Stay in the Pressure Chamber at at a Height m.

The data given provide a basis for assuming that in the latter case for subject P-v there was a progressive weakening of the simulation process. This is also indicated the the deterioration in the general conditions of the subject, so that it was necessary to conclude the experiment on the fifth day. A similar picture was also observed in the case of subject D-v, who was also following regime No. 2 and who terminated the experiment on the 10th day. The information within the range studied (3000-7000 m) does not have a clearly defined influence on man. The functional changes in the organism depended considerably on the length of stay at the height. Thus, in experiments involving a 30-day stay, a moderately pronounced but regularly increase in the pulse rate amounting to 10-15 beats per minute was observed beginning on the 14th or 15th day. This pulse rate either was maintained until the end of the experiment or continued to increase.

Data obtained from an orthostatic test also indicates increased excitability of the cardiovascular system in subjects during prolonged experiments. Thus, in the first 10-15 days of the stay in the pressure chamber the pulse rate for a given test increased by 10-35%, and during subsequent days, by 50%. At the same time there was a more pronounced increase in the arterial pressure as well. The changes noted were more pronounced in persons during wakefulness at night (regime No. 2). According to literature data, this kind of reaction indicates the onset of fatigue resulting from disturbances of the daily rhythm [3, 5, 6, 8]. /275

Disturbance of the relationship of stimulation and inhibition processes is also indicated by the data given earlier concerning certain visual functions and the variability of the delayed time reflex. The general direction of these changes tends toward a certain relative predominance of the stimulation process (increase in pulse rate and arterial pressure, increase pulse excitability in orthostatic tests, increased critical frequency of flicker fusion, etc.).

This trend of change is also indicated by a certain increase in the content of 17-oxycorticosteroids in the daytime urine and an increase in the albumina of the blood plasma (12%). The globulins, except for the α-globulins, usually decrease.

The changes mentioned above can be considered as possible indications of developing fatigue, resulting from incomplete functional restoration during the time devoted to rest through the day.

Since the subject followed different regimes of sleep and rest, it is of interest to consider separately the question of the nature of the changes in the daily rhythm of functions under the conditions of the experiment.

In the case of regime No. 1, which was the more usual regime, in most experiments the daily periodicity of functional changes (pulse frequency and breathing rate, arterial pressure, and body temperature) was quite clearly defined (Fig. 6). Minimum values were usually recorded during sleep at night, and maximum values during the day when the subject was awake. /276

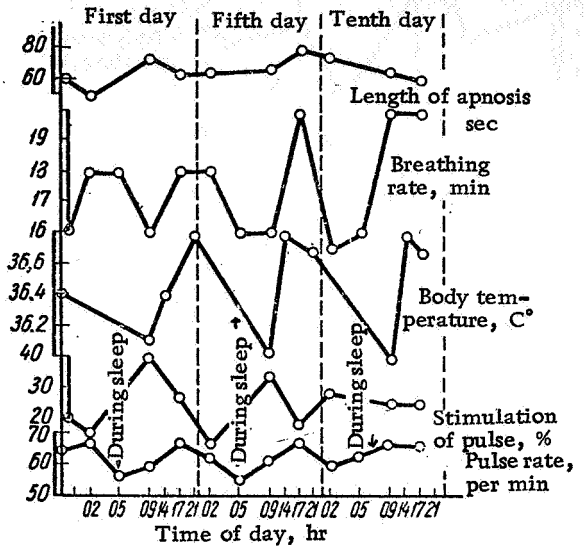

Figure 6. Daily Variations of Certain Physiological Indexes in Subject Pod-v on the Second, Fifth, and Tenth Days of the Experiment. Height 7000 m, Regime No. 1.

In the case of the other less favorable regime (No. 2) the daily periodicity of the functions studied was not so smooth, but often was even distorted (Fig. 7). Thus, for example, in the case of subject P-v the pulse frequency and breathing rate and body temperature were often greater during sleep than during wakefulness.

Daily periodic fluctuations in the EEG were observed in subjects following both regime No. 1 and regime No. 2. α and β_n rhythms were quite pronounced during wakefulness in the daytime. The α rhythm was regularly intensified when the eyes were closed. The frequency of the α rhythm was quite clearly defined for every subject during wakefulness. The slow EEG rhythms δ and θ were regularly observed during wakefulness (Fig. 8). But because of the masking effect of the higher frequencies, the slow rhythms were difficult to analyze visually, and this could only be done by special frequency analysis.

The total EMF of the EEG and the EMF of the frequency spectra for every subject were quite constant at a particular time of day. Minimum EMF of the EEG was usually observed in the morning, and maximum at night during sleep.

It is interesting to note that in the case of regime No. 2 the EEG recorded during wakefulness at night showed a shift of the dominant frequency toward slower variations.

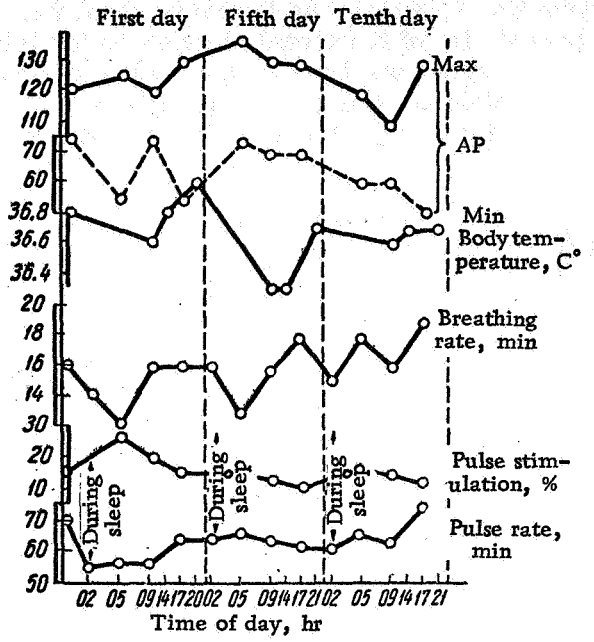

Figure 7. Daily Variations of Certain Physiological Indexes in Subject P-v. Height 5000 Regime No. 2.

The studies carried out show that a change in the ordinary daily regime involves a disturbance of the normal daily periodicity of physiological processes. The practical significance of this fact, which was also noted previously under other experimental conditions [1, 2, 7] means that special studies must be carried out to find appropriate regimes of sleep and wakefulness for crews of /277 spaceships. In this regard it should be emphasized that more than just the length of time devoted to sleep must be taken into account for proper choice of the best regime. Experimental information available thus far indicate that wakefulness during the night (from 3 to 6 hr), i.e., during the usual daily period of deepest sleep, has a deleterious effect on capacity for work.

We still have absolutely no experimental information on the role of interoceptive and proprioceptive impulses, and their relationship to gravitational forces. The condition of weightlessness evidently can have a substantial influence on the dynamics of fundamental nervous processes, and these in the last analysis also determine the periodic character of changes in the functional state of the organism, including the succession of periods of sleep and wakefulness.

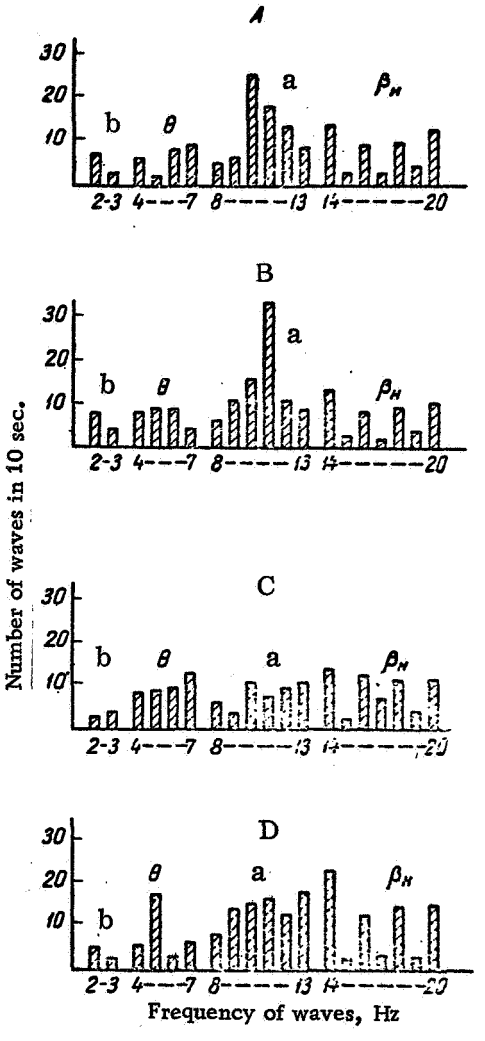

Figure 8. EEG Spectrogram of Subject F-k (Regime No. 2) as Recorded at 10 AM (A), 2 PM (B), 1 AM During Sleep (C), and 5 AM During the Time of Nocturnal Wakefulness (D).

The gas exchange of the subjects merits study in order to evaluate the conditions of the experiment—the degree of rarefaction and the length of stay. Studies conducted in this regard have shown that prolonged stay in a pressure chamber is accompanied by a decrease of 20% or more in the gas exchange of the subjects as compared with the initial value. /278 The reduction in gas exchange was more pronounced in persons following regime No. 1, and it did not depend on the degree of rarefaction in the pressure chamber. The significant reduction in the total activity of the subjects can be considered as the very probable cause of the reduction in gas exchange.

Protein, fat, and carbohydrate metabolism studied during the experiment did not vary appreciably. Somewhat different data were obtained on the cholesterol metabolism. In the experiment carried out at heights of 5000-7000 m, the cholesterol content of the blood increased 100-150 mg % on the eighth day of the stay in the pressure chamber. More detailed data concerning changes in metabolic processes will be given in special communications.

Several changes worthy of attention were observed as a result of clinical examination of persons participating in the experiment. Even during the sojourn in the pressure chamber a slight increase was observed in the latent period (4-20 sigmas) and amplitude of the patellar reflex. The magnitude of the static reflexes (cephalogram) increased (from 3 to 8 mm). Unconditioned vascular reflexes during the after effect period increased in some cases, decreased in other cases, and somtimes were reversed. These variations were not found to depend on the degree of rarefaction and the length of stay in the pressure chamber.

Phenomena of hypertonia were often observed in the persons examined during the aftereffect period: maximum arterial pressure dropped to 90 mm Hg, and minimum to 35-40 mm Hg.

Study of arterial pressure, systolic and cardiac output, and the rate of propagation of the pulse under conditions of rest and exertion indicate some loss of conditioning of the cardiovascular system which was more clearly evident after the 30-day experiment.

This probably also is to be explained by the prolonged limitation of movement of the subject. Hence we are faced with the need for developing a special set of physical exercises to maintain overall functional tone of the organism at sufficiently high level during the time a man remains under conditions which restrict his overall activity and movement [4].

Phenomena related to loss of functional tone were less pronounced in persons who participated repeatedly in prolonged experiment. This gives us reason to suppose that special training is desirable for situations of this sort. /280

Our studies also showed that the personality characteristics of the subjects are not the least important factor to be considered in setting up experiments involving prolonged stay of several subjects in a small chamber.

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